Astronomy & Astrophysics manuscript no. Ga282
(DOI: will be inserted by hand later)

February 2, 2008

Spectral evolution of weak bursts from SGR 1806–20 observed with INTEGRAL*

D. Götz[1,2], S. Mereghetti[1], I.F. Mirabel[3,4], and K. Hurley[5]

[1] Istituto di Astrofisica Spaziale e Fisica Cosmica – CNR, Sezione di Milano "G.Occhialini", Via Bassini 15, I-20133 Milano, Italy
[2] Dipartimento di Fisica, Università degli Studi di Milano Bicocca, P.zza della Scienza 3, I-20126 Milano, Italy
[3] Service d'Astrophysique, CEA/Saclay, Orme des Merisiers Bât. 709, F-91191 Gif-sur-Yvette, France
[4] Instituto de Astronomia y Fisica del Espacio / CONICET, cc67, suc 28. 1428 Buenos Aires, Argentina
[5] UC Berkeley Space Sciences Laboratory, Berkeley CA 94720-7450, USA

the date of receipt and acceptance should be inserted later

Abstract. We report on bursts from the Soft Gamma-Ray Repeater SGR 1806–20 detected with INTEGRAL in October 2003, during a period of moderate activity of the source. The spectral and temporal properties of 21 short bursts are consistent with those found in previous observations, even if these bursts are among the faintest observed in the 15-200 keV range from this source. During some of the bursts a clear spectral evolution is visible. The data also show, for the first time, evidence for a hardness-intensity anti-correlation within SGR 1806–20 bursts.

Key words. Gamma Rays : bursts - Gamma Rays: observations - pulsars: general - stars: individual (SGR 1806-20)

1. Introduction

Soft Gamma-ray Repeaters (SGRs) are a class of peculiar high-energy sources discovered through their recurrent emission of soft γ-ray bursts. These bursts have typical durations of ~0.1 s and luminosities in the range 10^{39}-10^{42} ergs s^{-1} (see Hurley 2000 for a review of this class of objects). The bursting activity and the persistent emission observed in the ~0.5-10 keV energy range are generally explained in the framework of the "Magnetar" model (e.g. Duncan & Thompson 1992, Thompson & Duncan 1995), as caused by a highly magnetized (B ~10^{15} G) slowly rotating ($P \sim$ 5-8 s) neutron star.

SGR 1806–20 is one of the most active Soft Gamma-ray Repeaters. Here we report new observations of this source obtained with the INTEGRAL satellite in October 2003 during a period of bursting activity (Götz et al. 2003a, Hurley et al. 2003, Mereghetti et al. 2003b, Götz et al. 2003b). These data have two advantages compared to previous observations in the soft γ-ray energy range of bursts from this source. First, they have been obtained with an imaging instrument, thus we can exclude that the bursts originate from a different source in the field. Second, they have a good sensitivity and time resolution which allows us to study the spectral evolution of relatively faint bursts.

2. Observations and data analysis

The region of SGR 1806–20 was observed by INTEGRAL (Winkler et al. 2003) between October 8 and 15 2003 as part of the Core Program deep observation of the Galactic Centre, yielding an exposure of about ~480 ks on the source. Several bursts from the direction of SGR 1806–20 were detected in near real time by the INTEGRAL Burst Alert System (IBAS, Mereghetti et al. 2003a), using data from the IBIS instrument (Ubertini et al. 2003). IBIS, a coded mask telescope with a large field of view ($29^\circ \times 29^\circ$), comprises two detector layers: ISGRI (15 keV - 1 MeV, Lebrun et al. 2003) and PICsIT (170 keV - 10 MeV, Labanti et al. 2003). Only ISGRI data are relevant here, since PICsIT does not have enough time resolution for the study such short bursts.

In total, 21 bursts were detected by the IBAS programs. By means of images accumulated over the time intervals corresponding to the individual bursts, we can be confident that all of them originated from SGR 1806–20 . In fact, the derived coordinates are all within 2′ from the well known position of SGR 1806-20 (Kaplan et al. 2002), while the 90% confidence error circle is typically of the or-

Send offprint requests to: D. Götz, email: diego@mi.iasf.cnr.it

* Based on observations with INTEGRAL, an ESA project with instruments and science data centre funded by ESA member states (especially the PI countries: Denmark, France, Germany, Italy, Switzerland, Spain), Czech Republic and Poland, and with the participation of Russia and the USA.

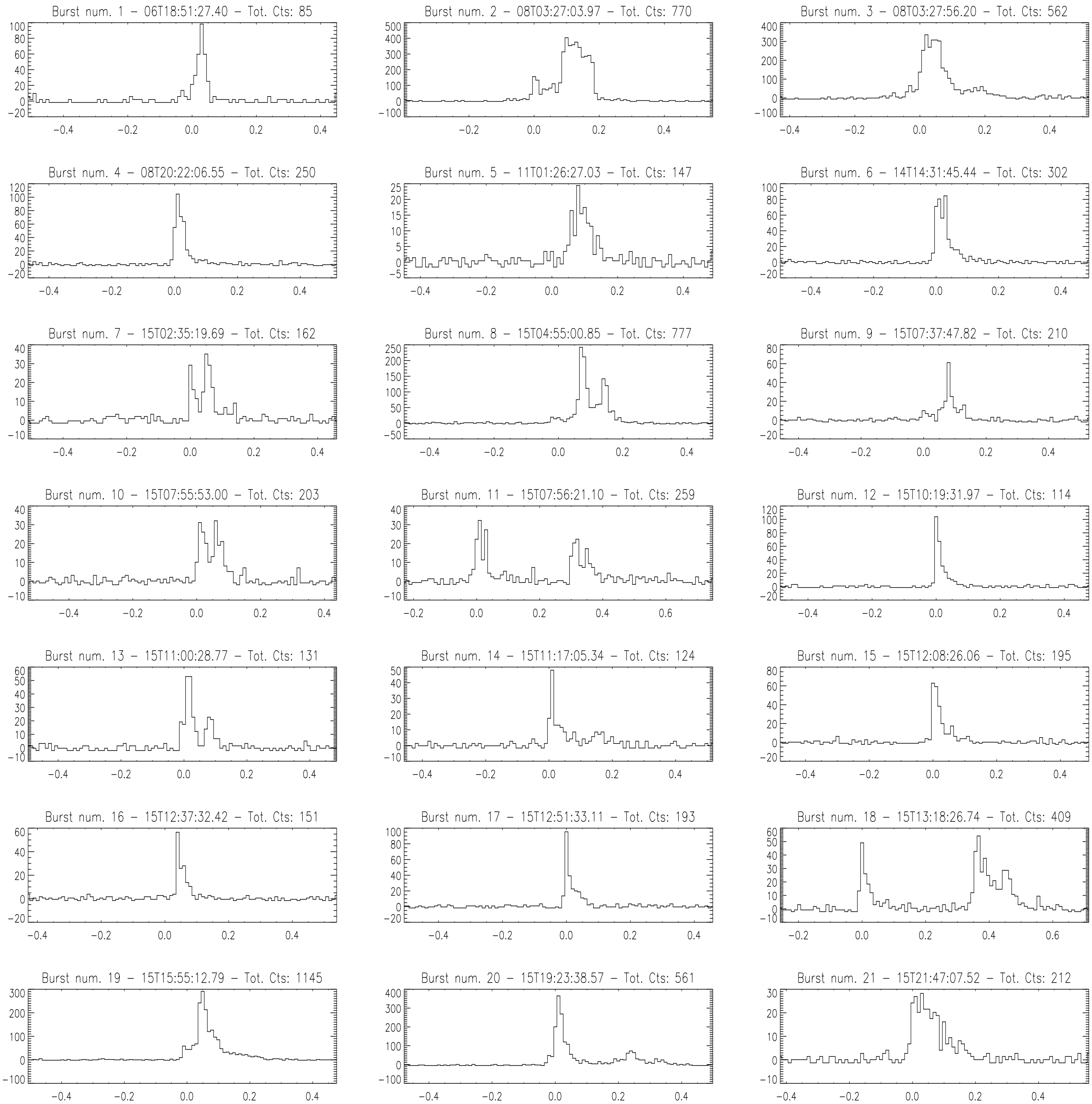

Fig. 1. IBIS/ISGRI background subtracted light curves of the SGR 1806-20 bursts in the 15-100 keV range. Each panel corresponds to a time interval of one second and the time bins are of 10 ms. Units of the axes are time in seconds and vignetting corrected counts per bin. Time 0 corresponds to the the starting time of the T_{90} computation and is reported on top of each panel together with the total number of net counts.

der of 2.5′. In particular, the bursts positions are not consistent with the possible SGR 1808-20 (Lamb et al. 2003) recently discovered at 15′ from SGR 1806–20 .

The background subtracted light curves of the bursts, binned at 10 ms, are shown in Fig. 1. In order to increase the signal-to-noise-ratio, they were extracted from ISGRI pixels illuminated by the source for at least half of their surface and selecting counts in the 15-100 keV energy range (most of the bursts had little or no signal at higher energy). The bursts were detected at various off-axis angles, ranging from 2.5 to 13.3 degrees, corresponding to a variation of 80% in the instrument effective area. The light curves shown in Fig. 1 have been corrected for this vignetting effect. The total number of net counts actually recorded for each burst is indicated in the corresponding panel.

The light curves shown in Fig. 1 have shapes typical for SGR bursts. From the light curves we determined the

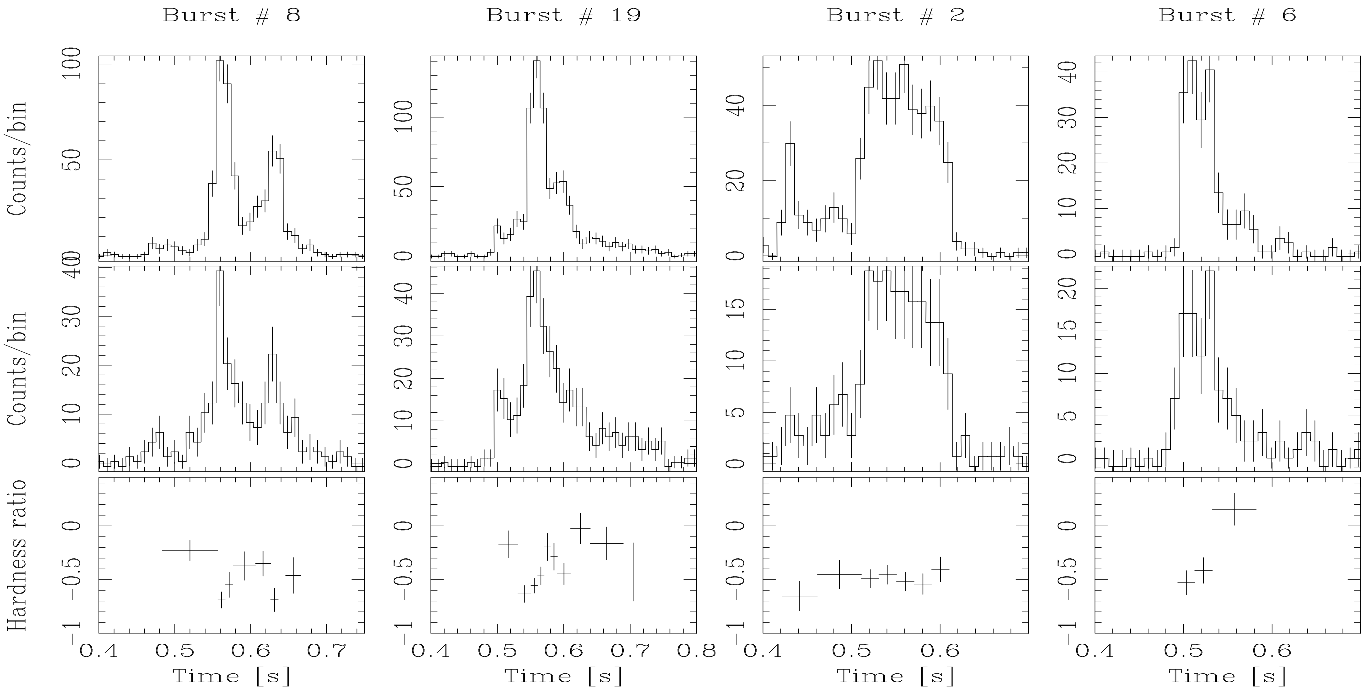

Fig. 2. 15-40 keV light curve (*Top Panels*), 40-100 keV light curve (*Middle Panels*), time resolved hardness ratio (*Bottom Panels*) for four bursts with good statistics. The time resolved hardness ratio for bursts number 8,19,6 is inconsistent with a constant value at $\sim$3.5 σ level.

T_{90} duration of each burst (i.e. the time during which 90% of the total burst counts are accumulated). The T_{90} values range typically from $\sim$0.1 to $\sim$0.2 s for single peaked bursts and can be as long as $\sim$0.6 seconds for double peaked bursts. In fact the T_{90} values of these bursts include the "interpulse" period. Some bursts are preceded by a small precursor.

The peak flux and fluence for each burst were first derived in counts units from the light curves of Fig.1, and then converted to physical units adopting a constant conversion factor derived from the spectral analysis of the brightest bursts (see next section). The resulting 15-100 keV peak fluxes and fluences are respectively in the range (4–50)$\times10^{-7}$ erg cm^{-2} s^{-1} (Δt=10 ms) and (2–60)$\times10^{-8}$ erg cm^{-2}. Within the large uncertainties, the fluence distribution is consistent with the power law slope found by Göğüş et al. (2000). Many of these bursts are among the faintest ever detected from SGRs at these energies.

2.1. Spectral properties

For the bursts with more than 500 net counts we could perform a detailed spectral analysis. The 15-200 keV spectra, integrated over the whole duration of each burst, were well fitted by an Optically Thin Thermal Bremsstrahlung (OTTB) model, yielding temperatures in the range from 32 to 42 keV. We tried other models, like a power law or a black body, but they were clearly ruled out.

Adopting a temperature kT=38 keV (consistent with the average spectra of the brightest bursts) we derived a conversion factor of 1 count s^{-1} = 1.5$\times10^{-10}$ erg cm^{-2} s^{-1} (15-100 keV), which we adopted for all the bursts.

To investigate the time evolution of the burst spectra we computed hardness ratios, defined as $HR = (H - S)/(H + S)$, based on the background subtracted counts in the ranges 40-100 keV (H) and 15-40 keV (S). The time resolved HR values were computed for all the bursts with more than 200 net counts (i.e. for 12 bursts of our sample). The duration of the individual time bins were chosen in order to have at least 80 net counts in the total ($H+S$) band.

Some bursts show a significant spectral evolution, while others, particularly those with a "flat topped" profile, do not. Some examples are given in Fig. 2. While several bursts show a soft-to-hard evolution (e.g. number 6), others show a more complex evolution (eg. number 19).

We investigated the variation of the hardness ratio versus intensity (I). Considering all the time bins of all the bursts (see Fig. 3), we find a hardness-intensity anti-correlation. The linear correlation coefficient of the data plotted in Fig. 3 has a chance probability P smaller than 10^{-3} of being due to uncorrelated data. According to an F-test, the data are significantly ($\sim$5.2 σ) better described by a linear fit ($HR = 0.45 - 0.22 \times log(I)$) than by a constant value. The exclusion of the three "flat topped" bursts from the fit does not affect the statistical significance of the anti-correlation.

We also find an hardness-fluence anti-correlation over the entire fluence range of our bursts, although with a smaller statistical significance (P = 5$\times10^{-3}$), which is consistent with our hardness-intensity anti-correlation and

also with the results obtained with *RXTE* data at lower energies (Göğüş et al. 2001).

3. Discussion

Previous studies indicated weak or no spectral evolution for SGR bursts (e.g. Fenimore et al. 1994, Kouveliotou et al. 1987). Up to now indication for a hard-to-soft evolution has been reported only for a single burst from SGR 1806–20 (Strohmayer & Ibrahim 1998) and for a precursor to a long burst (3.5 s) from SGR 1900+14 (Ibrahim et al. 2001). The same kind of spectral evolution has also been reported for a ∼9 s long burst from SGR 0526-66 (Golenetskii et al. 1987): the softening trend is seen in the first three of the four spectra extracted, while the last one is as hard as the first one. In our sample we do not find evidence for this kind of evolution.

On the other hand, soft-to-hard evolution has been seen with the BATSE instrument for two peculiar bursts very likely originating from SGR 1900+14 (Woods et al. 1999). These two bursts were quite different from the usual bursts, both in terms of duration (lasting ∼ 1 s), and spectral hardness (kT of the order of 100 keV).

In the framework of the magnetar model (Duncan & Thompson 1992), short (∼0.1 s) SGR bursts are usually described as the radiation originating from the cooling of an optically thick pair-photon plasma. This plasma is generated in the neutron star magnetosphere by an Alfvén pulse, which is triggered by a sudden shift in the magnetospheric footpoints driven by a fracture in the neutron star crust (Thompson & Duncan 1995). This model is able to explain the time histories and energetics of the typical SGR bursts, and predicts that the effective temperature of the spectra should vary weakly during the bursts, owing to the constancy of the photospheric energy flux. No detailed predictions are available concerning more complex spectral evolution as we observe in some of the bursts. For example the model does not account for the presence of a soft precursor as observed in burst number 2 (see Fig. 2).

Our results indicate that a hardness-intensity anticorrelation (which in many bursts manifests itself as a soft-to-hard time evolution) is present in bursts from SGR 1806–20 which are not particularly long, nor spectrally hard and not at all very energetic. It is interesting to note that this correlation is opposite to what found for the bursts emitted from 1E 2259+586 (Gavrill et al. 2004), which although have lower fluences than the ones we measure.

Acknowledgements. This research has been supported by the Italian Space Agency.

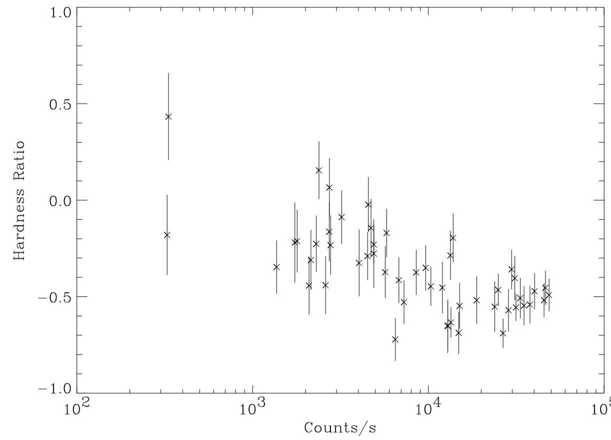

Fig. 3. Hardness-Intensity plot of the time resolved hardness ratios of the 12 bursts with the best statistics. The hardness ratio is defined as $(H - S)/(H + S)$, where H and S are the background subtracted counts in the ranges 40-100 keV and 15-40 keV respectively. The count rates are corrected for the vignetting and refer to the 15-100 keV range.

References

Duncan, R.C., & Thompson, C. 1992, ApJ, 392, L9
Fenimore, E.E., Laros, J.G., & Ulmer, A. 1994, ApJ 432, 742
Gavrill, F.P., Kaspi, V.M., & Woods, P.M. 2004, ApJ, in press, (astro-ph/0310852)
Göğüş, E., Woods, P.M., Kouveliotou, C., et al. 2000, ApJ, 532, L21
Göğüş, E., Kouveliotou, C., Woods, P.M., et al. 2001, ApJ, 558, 228
Golenetskii, S.V., Aptekar, R.L., Gur'yan, et al. 1987, Sov. Astron. Lett., 13, 166
Götz, D., Mereghetti, S., Beck, M., & Mirabel, I.F. 2003a, GCN, 2408
Götz, D., Mereghetti, S., Beck, M., & Mirabel, I.F. 2003b, GCN, 2419
Hurley, K. 2000, in AIP Conf. Proc. 526, 5th Hunstville Symp. on Gamma-Ray Bursts, ed. R.M. Kippen, R.S. Mallozzi, & G.F. Fishman (New York: AIP), 763
Hurley, K., Cline, T., Mazets, E., & Golenetskii, S. 2003, GCN, 2414
Kaplan, D.L., Fox, D.W., Kulkarni, S.R., et al. 2002, ApJ 564, 935
Kouveliotou, C., Norris, J.P., Cline, T.L., et al. 1987, ApJ, 322, L21
Ibrahim, A.I., Strohmayer, T.E., Woods, P.M., et al. 2001, ApJ, 558, 237
Labanti, C., Di Cocco, G., Ferro, G., et al. 2003, A&A, 411, L149
Lamb, D., Graziani, C., Shirasaki, Y., et al. 2003, GCN, 2351
Lebrun, F., Leray, J.P., Lavocat, P., et al. 2003, A&A, 411, L141
Mereghetti, S., Götz, D., Borkowski, J., Walter, R., & Pedersen, H. 2003a, A&A, 411, L291
Mereghetti, S., Götz, D., Beck, M., & Mirabel, I.F. 2003b, GCN, 2415
Strohmayer, T., & Ibrahim, A. 1998, in AIP Conf. Proc. 428, Fourth Hunstville Symp. on Gamma-Ray Bursts, ed. C.A. Meegan, R.D. Preece, & T.M. Koshut (Woodbury: AIP), 947
Thompson, C., & Duncan, R.C. 1995, MNRAS, 275, 255

Ubertini, P., Lebrun, F., Di Cocco, G., et al. 2003, A&A, 411, L131
Winkler, C, Courvoisier, T.J.-L., Di Cocco G., et al. 2003, A&A, 411, L1
Woods, P.M., Kouveliotou, C., van Paradijs, J., et al. 1999, ApJ, 527, L47